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SMALL SCALE TECHNIQUE FOR MEASUREMENT OF DETONATION VELOCITIES

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ABSTRACT: This report describes the use of the vacuum thermocouple microsecond timer to measure detonation velocities of some common explosives. Problems such as diameter effect, inherent in the use of small quantities of explosives in these measurements, are discussed. It is concluded that ample radial confinement can reduce the effect of small diameters to such an extent that a good estimate of the detonation velocity of an explosive can be obtained with this timer.

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A small scale technique for determining rates of detonation is described in which the vacuum thermocouple timer, reference (a), developed here is used. The method is advantageous in the early stages of development of new explosives when only small quantities are available. The method has the other advantages concomitant with small scale measurements. The rates of detonation of standard explosives are reported and compared with rates obtained by use of substantially larger quantities of explosives. The work was authorized by Task Assignment NOL-Re2c-1-1(EP)-52. This report is for information only and is not intended to be used as a basis for action.

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Introduction

In the development of new explosives, it is important to make an estimate of performance as reliable as possible while the preparation of a new compound is still in the laboratory stage. Such an estimate of performance made in the laboratory stage of development can save expense of time and money in preventing more extensive investigation of ineffective explosives. During laboratory development only small quantities of explosives are available for study. Consequently, the small scale technique for determining detonation rates described is valuable.

Although the relationships involved are well enough known to make possible calculations of performance based upon the chemical composition and heat of formation of a compound, these calculations depend upon assumptions regarding chemical equilibria and equations of state under conditions which cannot be obtained statically. It has been possible to determine the validity of such assumptions and to adjust the values of the constants involved using performance data of known explosives but this process has not been carried to the point where further checking is unnecessary in the case of new compounds. Some of the most usable performance data for such purposes are those relating the detonation velocity of a compound to its loading density. In addition, the detonation velocity is a nearly direct critierion of performance in certain applications, e.g. shaped charges.

The present report includes an account of the development of a technique for measuring the detonation velocity of explosives for which only small samples are available together with some data obtained by this method with standard explosives and a comparison of these values with data obtained by other observers using larger samples.

Experimental Apparatus and Procedures

General Discussion:

Briefly, the method consists of the measurement of the time required for the detonation of a small, highly confined column of explosive to traverse the distance between two accurately spaced probes. The column diameters used have been 0.10, 0.15, and 0.20 inch and the length has, in general, been one inch. The diameter effect has been reduced by high radial confinement. The time is measured by means of a vacuum thermocouple microsecond timer as described in reference (a).

Figure 1 shows the explosive column ready for firing. The V block and clamping arrangement facilitate the alignment of the various sections

of the explosive column and make it possible to reduce the spacing between elements of the column to a known minimum. The wood protects the metal parts from the direct action of the explosive.

Figures 2 and 3 show alternate electrical systems which were used on the probes. That shown in Figure 2 was used at first, but a change was made to that shown in Figure 3 when timing circuits of the last design discussed in reference (a) had been constructed. In both circuits, the ionized gas of the detonation front completed the circuits to give start and stop signals. It is the practice to check the calibration of the timer at frequent intervals using coaxial cable as a time standard. Two timers were used for each measurement. Figure 4 is a photograph of the complete apparatus for firing and measuring.

Time Measurement:

The instrument used for measuring time in these experiments is discussed in detail in reference (a). Essentially it consists of two thyratrons which deliver to the heater of a vacuum thermocouple a square electrical pulse of reproducible amplitude with a duration equal to the time to be measured. The temperature rise of the heater, as measured by the thermocouple, is used as a measure of the time.

Inasmuch as the calibration of the instrument varies slightly over periods from day to day or even over a few hours frequent calibrations were made using coaxial cables of various lengths as time standards. The coaxial cables were calibrated by determining resonant and null points with the help of a tuned circuit oscillator which was, in turn, checked against a crystal controlled oscillator.

The transit times, as determined by this method, decreased slightly with increasing frequency. The frequencies used, one-tenth to ten megacycles, were too low for separation of phase and group propagation rates, due to the geometry of the cable, to have a noticeable effect. It has been suggested that the slight reduction of transit times may be the result of polar components of the dielectric constant of the insulating material of the cable, the contribution of which decreases with increasing frequency. If so, the effect would be similar for both phase and group velocities.

Since there are undoubtedly components of the pulses used to calibrate the timer which exceed considerably the highest frequencies used in calibration of the cable, it is possible that the true times for physical phenomena are shorter than those indicated by measurements based upon such calibrations. This may account for part of the discrepancy between detonation velocities as measured by the present technique and those measured by other methods. Further study of this matter is proposed.

Probes:

As stated previously, the time signals used to start and stop the timer result from the closing of electrical circuits by means of the

highly conductive ionized gases of the detonation front. To accomplish this result, the gases must simultaneously contact two metallic conductors which are referred to herein as "probes". The axial position of these probes must be determined accurately. They must be rather close to the center line of the detonating column of the explosive for the reason that the detonating front of small charges may have considerable curvature. They must interfere as little as possible with the detonation which is being studied. Of course these requirements must be combined with reasonable convenience of construction and handling.

Figure 5 shows the construction of the probes which are used in these experiments. Each pair of probes consists of two flattened wires held between two pieces of Scotch vinyl film electrical tape. Number 24 plastic insulated stranded single conductor wires are used. Each conductor consists of seven No. 32 strands. The end of the wire is stripped for about an inch and the strands separated. All but one of the strands are cut off close to the insulation. The remaining strand is flattened in a small hand operated roller mill to about one mil thickness. Each piece of tape has a hole 2/3 to 3/4 of the diameter of the column of explosive with which it is to be used. The flattened ends of two wires are laid on the adhesive side of a piece of tape about 1/32" apart and straddling the center of the hole. This assembly is stuck to the back of another piece of tape so that the holes are aligned. The probe is now ready to apply to the end of the explosive specimen with the holes in the tape concentric with the explosive column.

The whole probe assembly is about six thousandths of an inch thick and the probes are quite near the center. In calculating velocities a correction of six thousandths of an inch is added to the length of the specimen.

Diameter Effects and Confinement:

It has been demonstrated repeatedly that small diameter charges detonate at lower velocities than larger columns. This diameter effect is negligible if all of the charges used are quite large but becomes increasingly important as the diameter is reduced until a "critical diameter" is reached below which stable detonation is unattainable. The critical diameter, as well as the diameter at which these effects become noticeable, varies quite considerably from one explosive to another. Thus, the value of data obtained with small diameter columns depends upon the elimination of such effects either in the experiment or its analysis.

The most obvious explanation for a diameter effect of this sort is that it is the result of radial losses of matter and energy. The hydrodynamic theory of the detonation process, reference (b), predicts that only conditions within the detonation zone can affect the detonation velocity. The ratio of the charge diameter to the reaction zone length thus becomes an important quantity. If this ratio is much greater than one

the radial losses from the reaction zone will be vanishingly small and the velocity will approach that for a charge of infinite diameter. Figure 6, taken from reference (d), shows the effect of diameter upon the detonation velocity of uncased charges.

In reference (b), Eyring and co-workers have discussed the effect which the diameter of the charge has upon the detonation velocity. In equation (50) of this reference a relation which may be written

$$\frac{D_1}{D_i} = 1 - \frac{K}{R_1}$$

is given, where D_1 is the detonation velocity in a charge whose radius is R_1, D_i is the detonation velocity for an infinitely large radius, and K is the product of the reaction zone length and the sine of the angle which the direction of the detonation at the circumference makes with the axis of the charge. If, as a first approximation, we assume that K is a constant we can derive an expression for D_i in terms of the detonation velocities of sticks of two diameters, R_1 and R_2

$$D_i = \frac{(rD_2 - D_1)}{(r - 1)}$$

where r is the ratio of R_2 to R_1. The value of K is actually a variable related to the detonation velocity but the above approximation should be fairly good if D_1 and D_2 do not differ greatly from each other. The amount of the diameter effect differs from one explosive to another. Figures 7 and 8 show data obtained by firing one tenth and two tenth inch diameter columns of two common explosives, TNT and RDX. As shown in this figure the estimate of the infinite diameter stick velocity obtained from this data is lower than data obtained from the streak camera for higher densities and is too high for low densities.

Encasing the explosive in a dense medium will, of course, result in reduced radial losses. The forces involved are so large that the strength of the confining medium is of little importance. The time is so short that the inertia of the confining medium becomes of critical importance. This would lead to the conclusion that the primary criterion of a good confining medium is its density. However, only that material which has been reached by the shock at any particular time has been accelerated so that the effective inertia of the confining medium is proportional to the product of its density and its shock velocity. This product is similar to the quantity known as "acoustic impedance". It will be referred to as "acoustic (shock) impedance".

Measurements have been made of the velocities of shocks in media near detonating high explosives but these measurements have dealt mainly

with normally impacting detonations from large charges. Although this may cast some doubt on their applicability to confining media of small charges, they are used to calculate the acoustic shock impedances quoted below.

TNT, which is more subject to diameter effects than most military explosives, was used to compare the effectiveness of several metals as confining media. The results are given below.

Table 1

Detonation Velocity of TNT*

Confining Material	Density	Shock Velocity	Acoustic Impedance	Detonation Velocity
Steel	7.85	5220	41	5950 m/sec
Copper	8.94	5335	47.7	5660
Lead	11.35	2730-3000	31.0-34.1	2500
Aluminum	2.70	7150-7850	19.3-21.2	1900

* Density 1.4

The detonation velocity of large columns of TNT at a density of 1.4 is approximately 6325 m/sec.

It will be noted that the columns confined in steel or copper show relatively little diameter effect while those confined in lead or aluminum show considerable loss in their detonation velocity. These results are in qualitative agreement with what might have been expected from the values of the acoustic impedances. The difference between steel and copper is not statistically significant nor is that between lead and aluminum as they are the means of only two or three shots. Moreover these abnormally low velocities are not very reproducible. Copper was used in the earlier experiments as a confining medium because copper components were available but the more recent work has been done using steel because of its better machining properties and lower cost.

Density Measurement:

The cavities into which the explosive was loaded were gaged with devices which were precise to the nearest 0.1%. The containers were weighed on an analytical balance before and after loading. Although these

measurements were read to the nearest 0.1 milligram the variations in atmospheric humidity cause changes of the order of one milligram in the weight of the containers so that the accuracy is less than the precision of measurements. For the 0.2 inch diameter columns which, in the one inch length, contain nearly a gram of explosive this error is small but for the 0.1 inch diameter it is more serious. However, it is still probably only a fraction of one percent.

Stabilization of Detonation:

When an explosive is initiated by a detonation of another explosive the resulting reaction usually does not proceed immediately at the normal detonation velocity of the explosive. The rate will depend upon the characteristic of the initiating explosive. However, the detonation velocity soon becomes stabilized or dies out. In a previous report, reference (c), data are reported which indicate that this stabilization takes place within the first half inch with column diameters of 0.10 inch and 0.20 inch with the explosive highly confined in metal.

In obtaining the data reported here the column of explosive, one inch in length, whose detonation velocity was being measured, was preceded, in most cases, by an inch of the same explosive loaded under the same conditions as that being tested. Thus, the detonation velocity had time to become stabilized before reaching the section under observation.

Conclusions

Measurements of detonation velocities of series of explosive samples loaded to different densities give velocities which depart very little from a linear relation to the density of the explosive. Calculations of the standard deviation of the departure from linearity for several runs indicate that a value of fifty to sixty meters per second is typical for this standard deviation. The high radial confinement minimizes the diameter effect until with some explosives very little difference can be noted between the velocities obtained for columns of one tenth and two tenths inches. With others, such as TNT, an estimate of the effect can be made.

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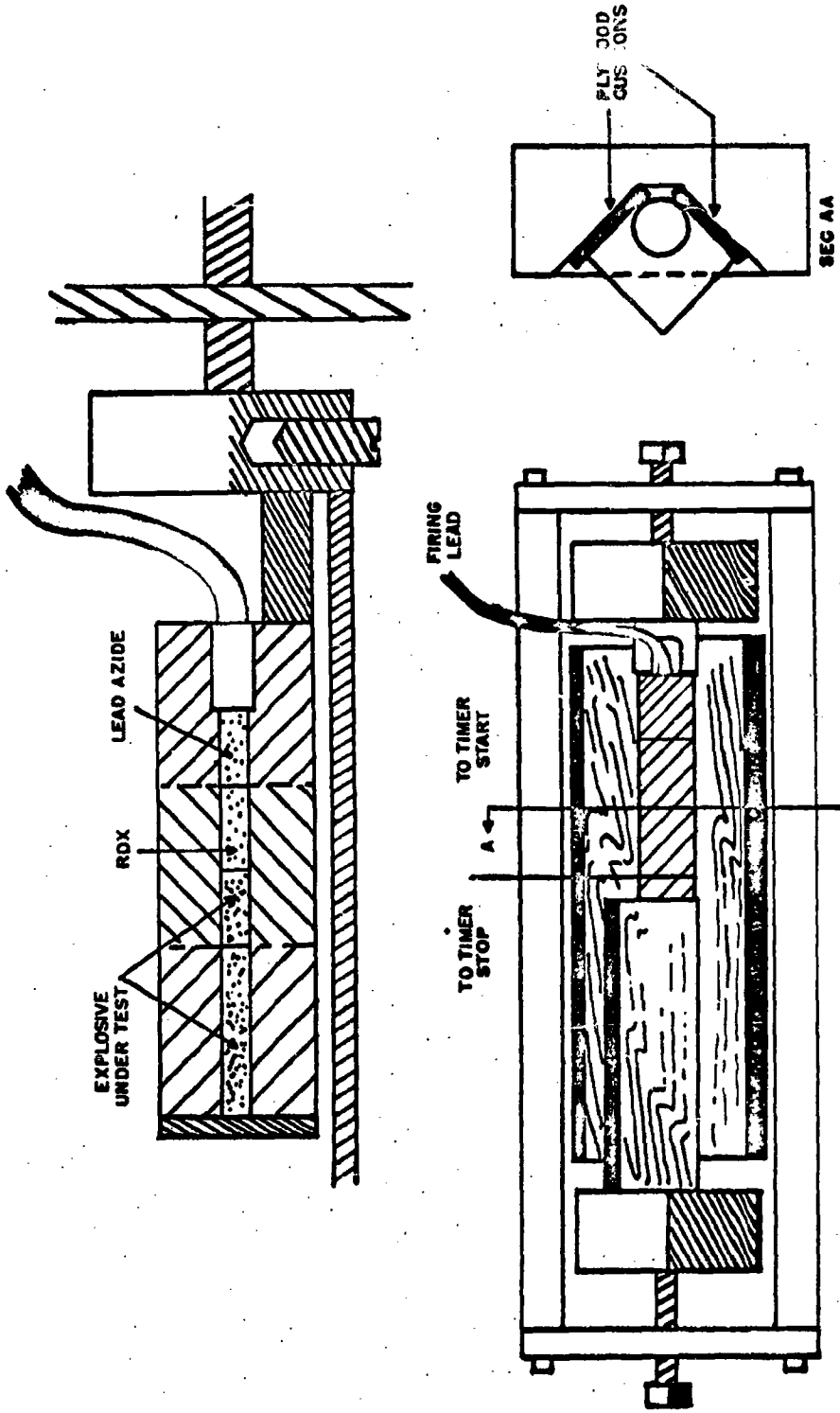


FIG.1 ARRANGEMENT OF EXPLOSIVE COLUMN

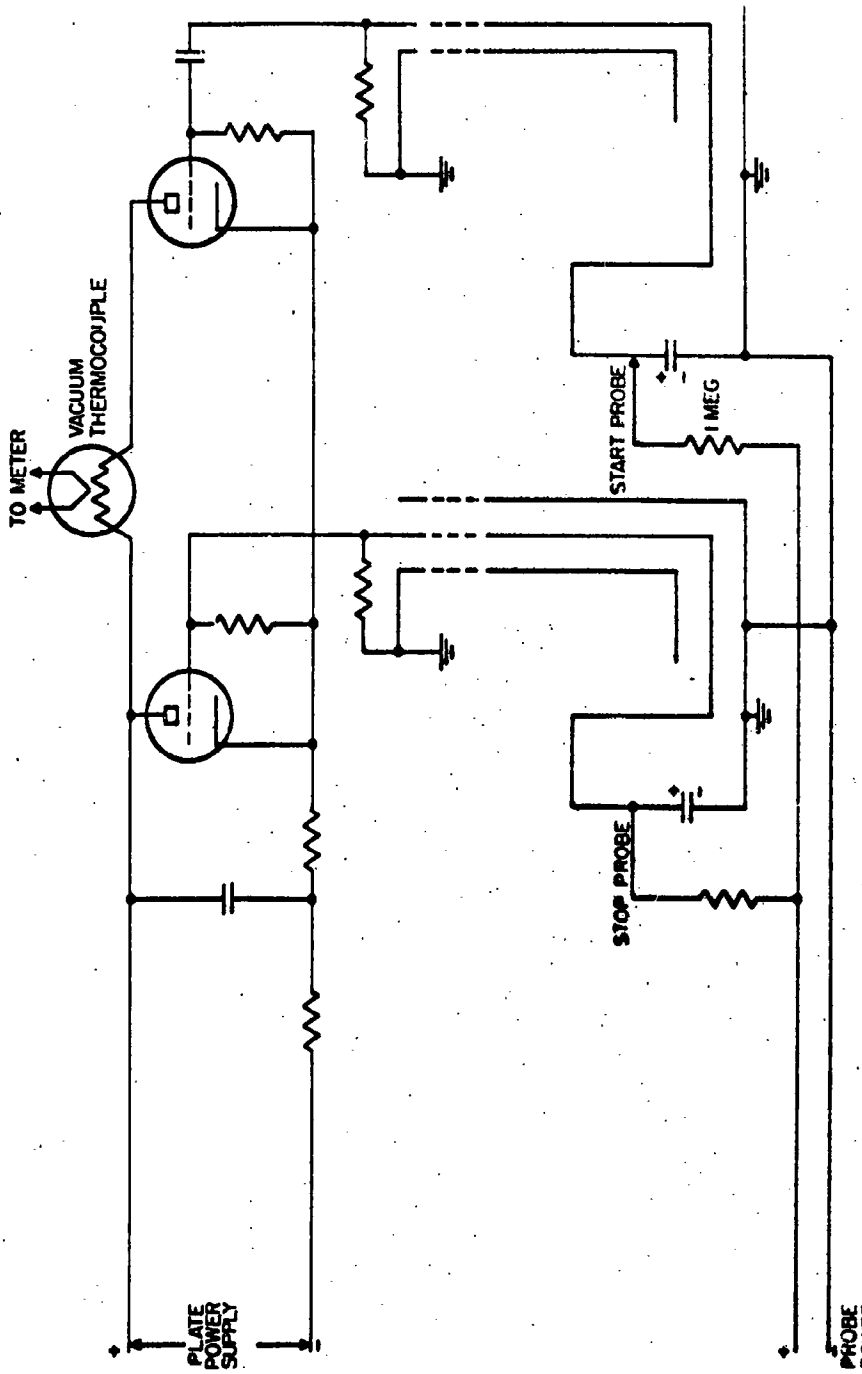


FIG. 2 ELECTRICAL CIRCUIT WITH EXTERNAL PROBE POWER SUPPLY

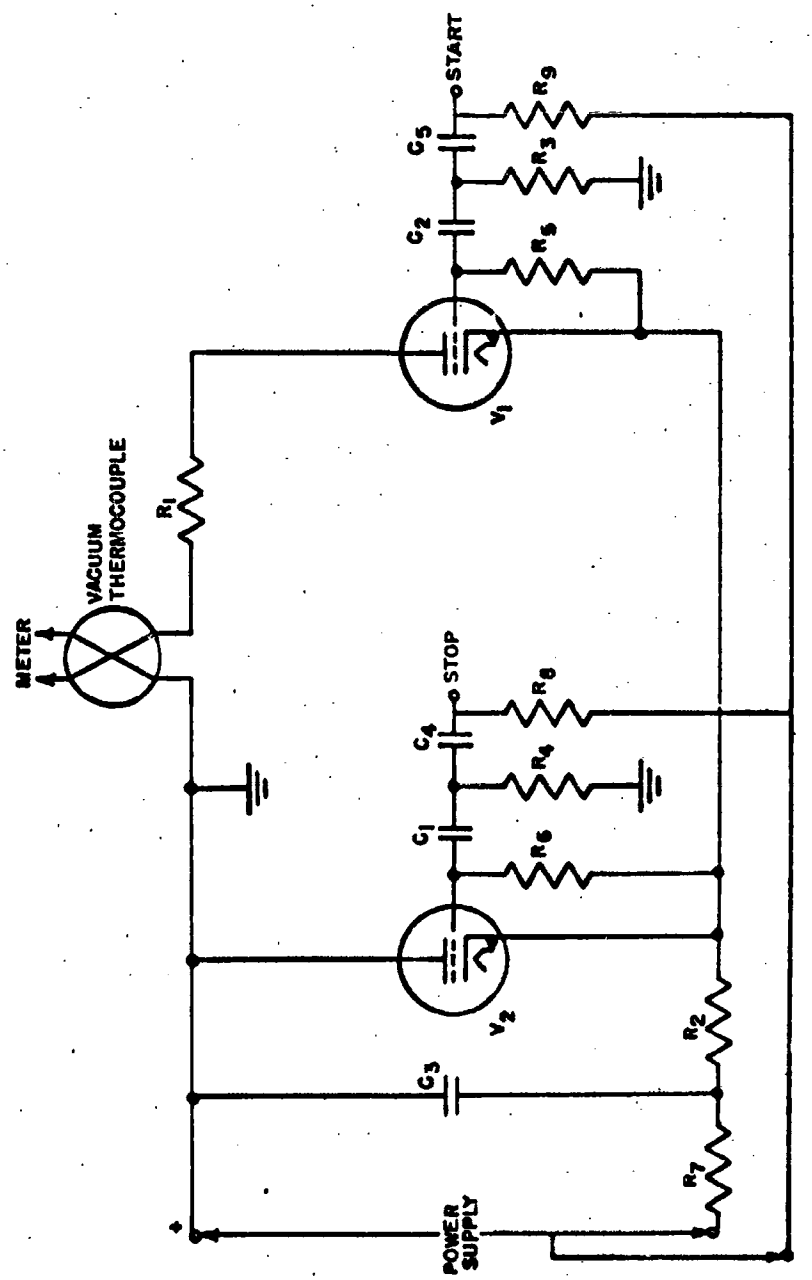


FIG 3 ELECTRICAL CIRCUIT WITH INTERNAL PROBE POWER SUPPLY

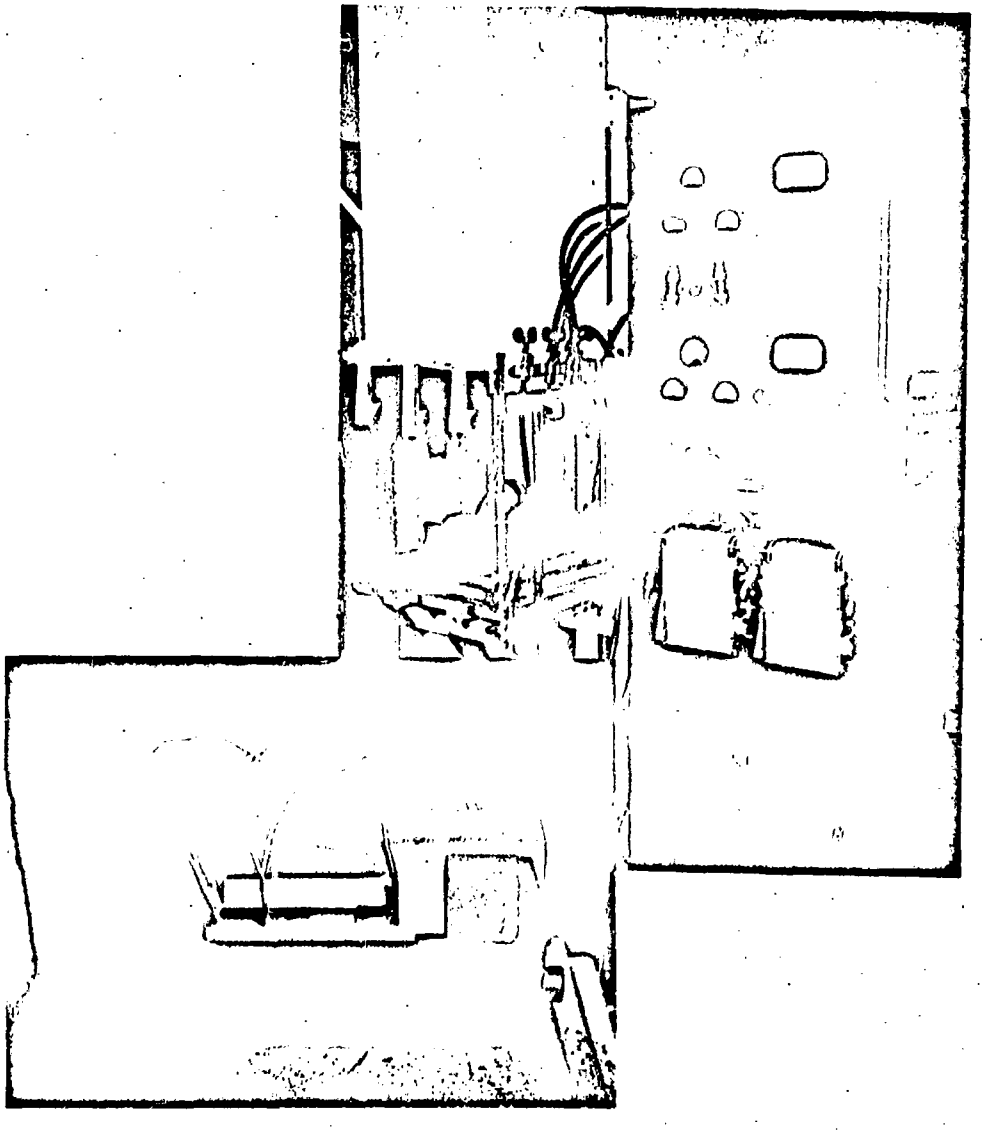


FIG. 4

ASSEMBLED EQUIPMENT

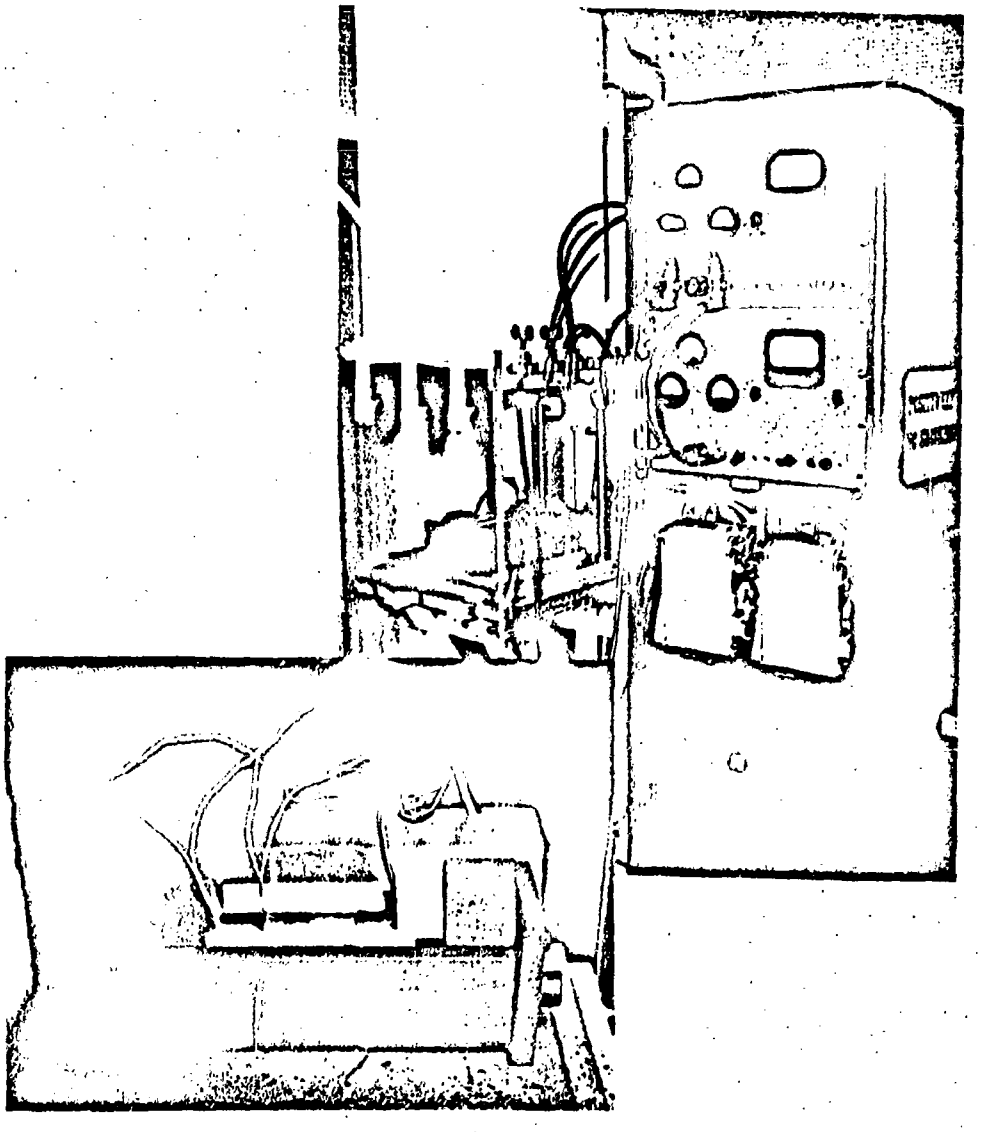
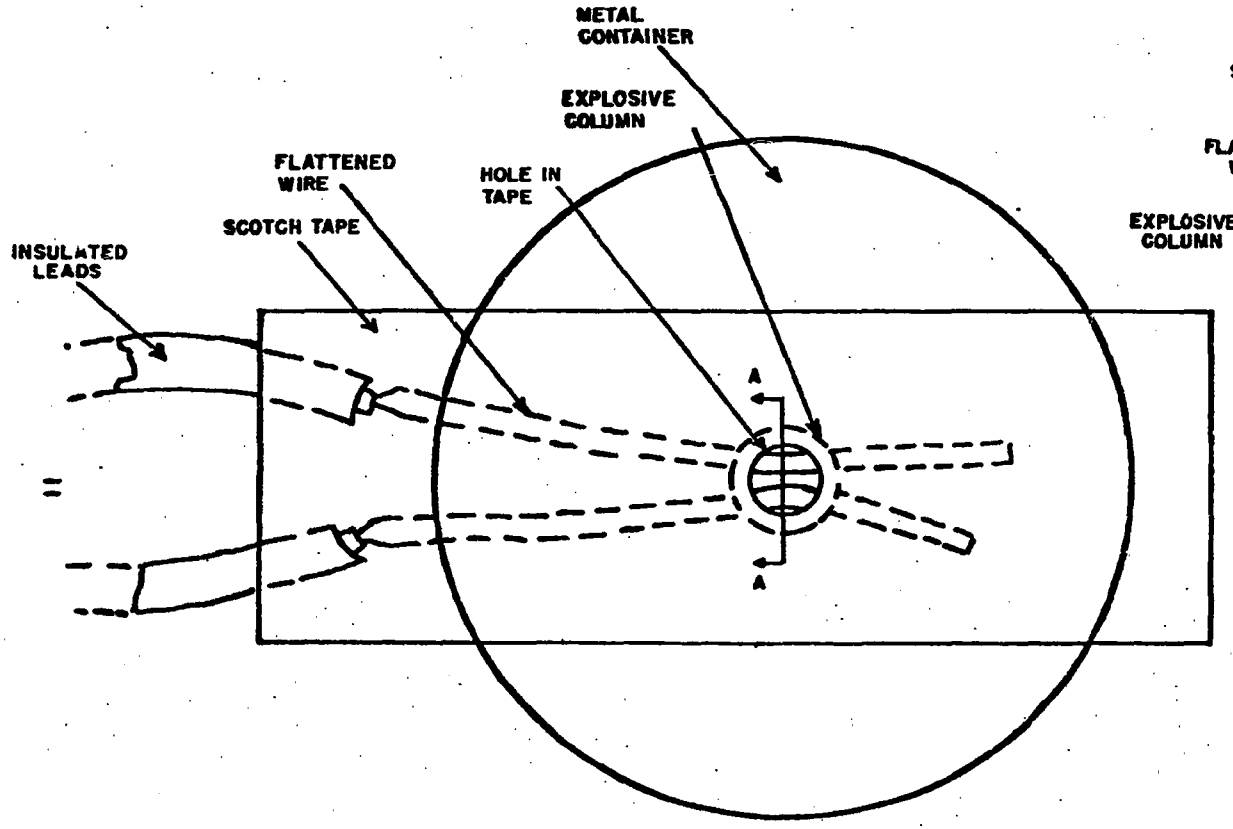


FIG. 4

ASSEMBLED EQUIPMENT



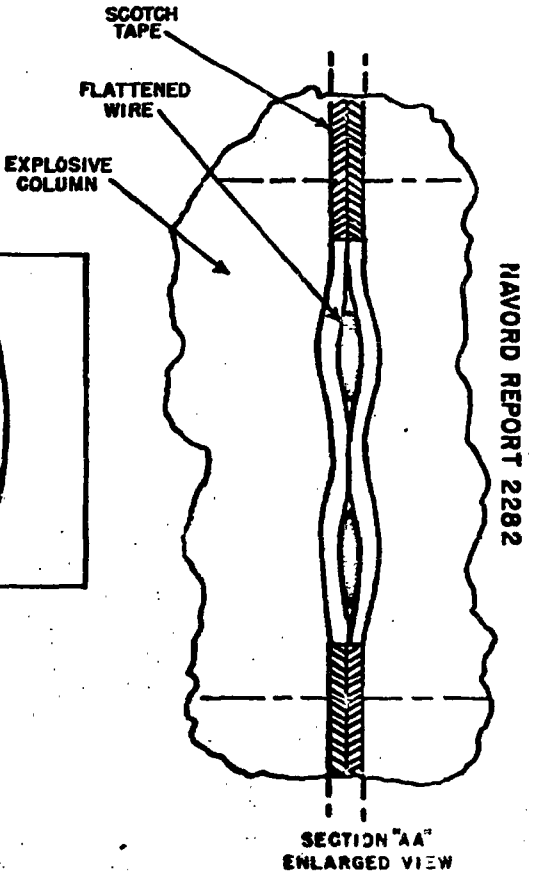


FIG. 5 PROBE CONSTRUCTION

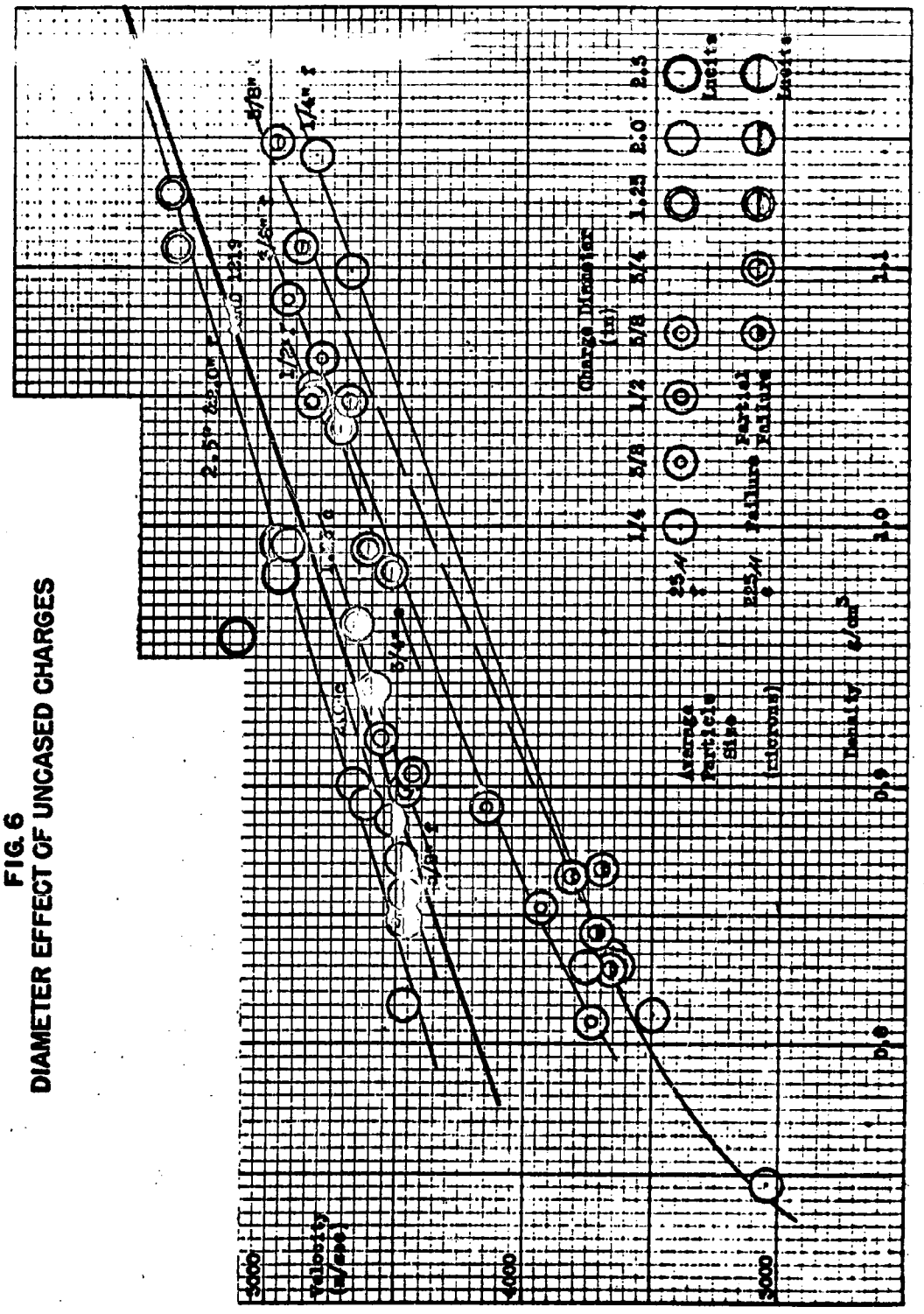


FIG. 6
DIAMETER EFFECT OF UNCASED CHARGES

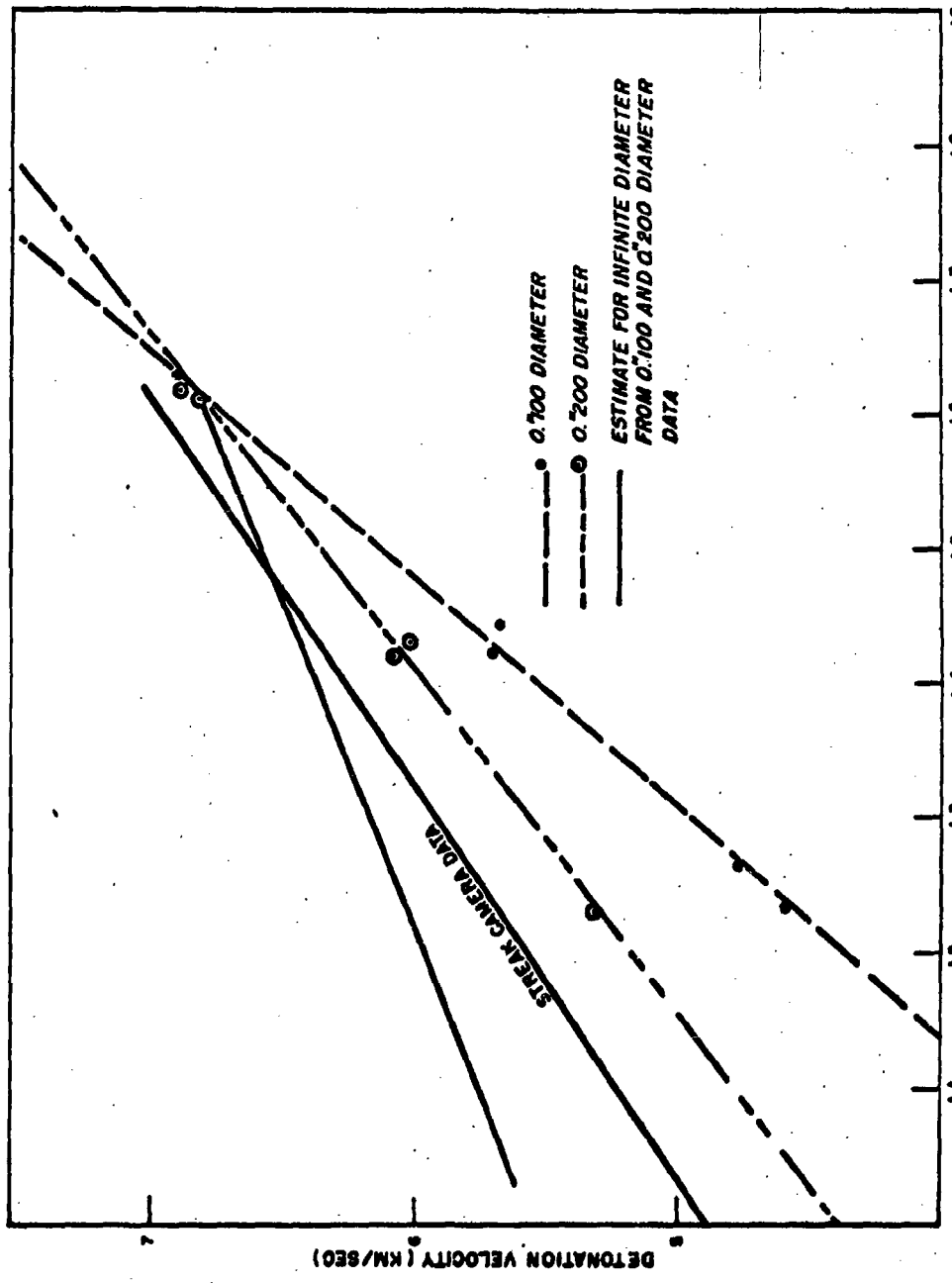


FIG. 7 DIAMETER EFFECT, TNT

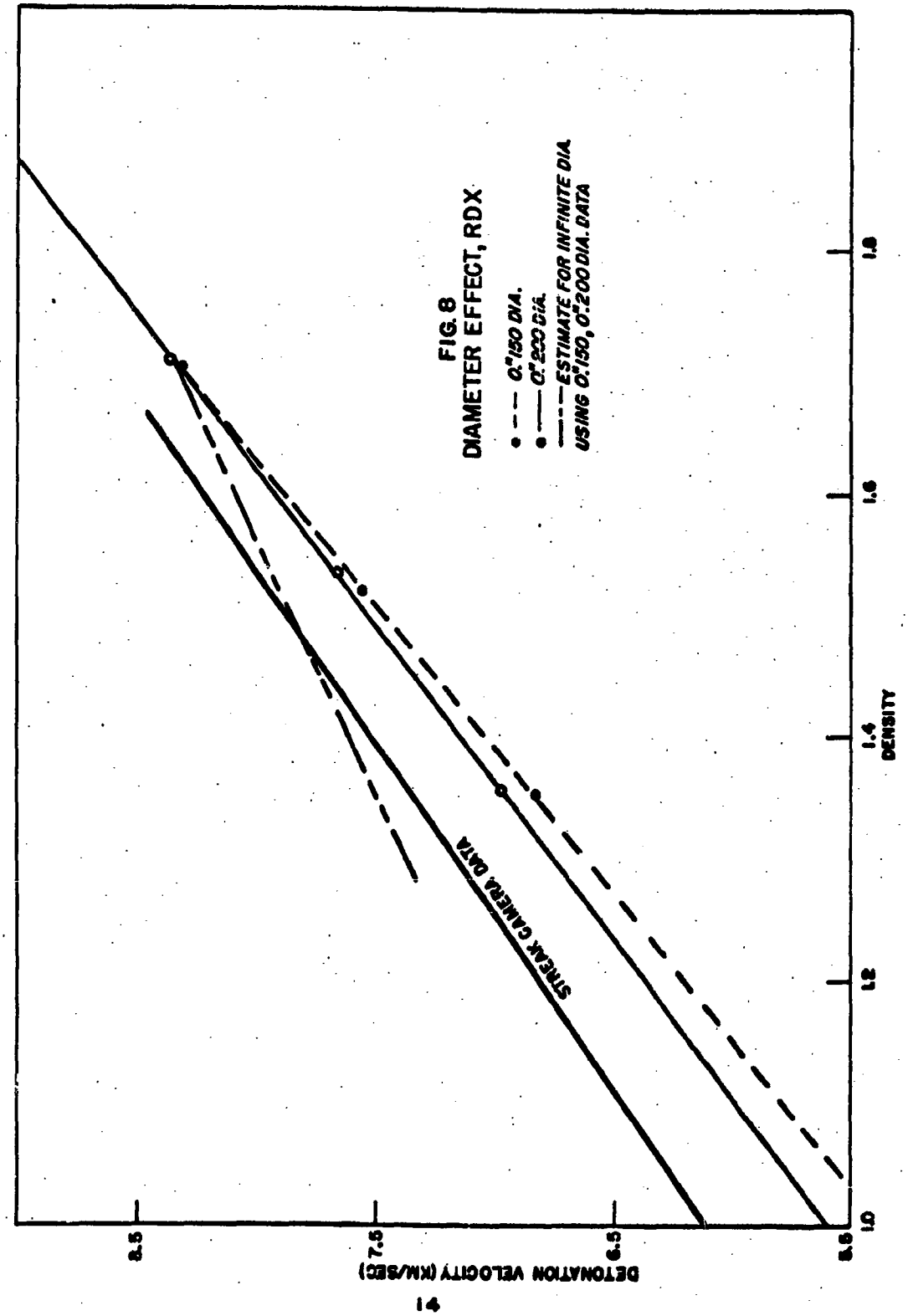


FIG. 8
DIAMETER EFFECT, RDX
• - - - 0".150 DIA.
• —— 0".220 DIA.
——— ESTIMATE FOR INFINITE DIA. USING 0".150, 0".200 DIA. DATA
STREAK CAMERA DATA
DETONATION VELOCITY (KM/SEC)
8.5
7.5
6.5
5.5
1.0
1.2
1.4
1.6
1.8
DENSITY

References

(a) NavOrd Report 2137, Recent Developments in the Vacuum Thermocouple Timer, 28 June 1951, R. H. Streeau and C. W. Goode

(b) Chemical Reviews, The Stability of Detonation, H. Eyring, R. E. Powell, G. H. Duffey and R. H. Parlin, Vol. 45, pp 69-181

(c) NavOrd Report 2135, Factors Affecting the Detonation Velocity of Selected Explosives, 19 July 1951, L. D. Hampton

(d) OSRD 5611, The Rate of Detonation of Various Explosive Compounds and Mixtures, 15 January 1946

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